# Enhanced Space Time Block Coded Spatial Modulation with Space-Time Trellis Codes For Sensing MIMO Technique

Bindhu Madhavi Aakella
M.Tech, E.C.E
S.R.K Institute of Technology
Vijayawada, A.P, India.

Naga Mani.Mendu
M.Tech, Asst.Professor
S.R.K Institute of Technology
Vijayawada, A.P, India.

***Abstract*— Multiple-input multiple-output systems have better performance under fading channels than single-input single-output (SISO) systems because of the huge capacity and reliability gains promised even in worst fading environment. This project presents the behavior of MIMO systems using STBC-SM scheme over Rayleigh Fading channel environments. MIMO transmission systems are investigated in terms of Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR) performance. BER vs SNR performance of STBC-SM systems are simulated for different number of transmitters using BPSK , QPSK and QAM modulation techniques and various equalization techniques such as Zero Forcing (ZF), Minimum Mean Square Error (MMSE) and Maximum Likelihood (ML). Results show the different error rate performance and channel capacity of a MIMO system using STTC scheme using QPSK modulation.**

Keywords-***Spatial Multiplexing, Space-Time Coding (STC); Orthogonal Frequency Division Multiple Access (OFDMA), Spatial Modulation.***

## I. INTRODUCTION

In the last decade, the study of wireless communications with multiple transmit and receive antennas has been conducted expansively in the literature on information theory and communications. It has been known from the information theoretic results that the application of multiple antennas in wireless systems can significantly improve the channel capacity over the single-antenna systems with the same requirements of power and bandwidth. Based on those results, many communication schemes suitable for data transmission through multiple-antenna wireless channels have been proposed, including Bell Labs Layered Space–Time (BLAST), space–time trellis codes, space–time block codes from orthogonal designs, and unitary space–time codes, among many others.

Information theory results show that the capacity of MIMO system increases linearly with the number of receive and transmit antennas respectively. However, for single-input single-output (SISO) channels, the capacity increases logarithmically with signal-to-noise ratio (SNR). Thus, a significant capacity increase can be achieved by MIMO systems without adding power and without expanding the bandwidth.

## II. CHARACTERISTICS OF MIMO

Wireless links in general suffer from a number of impairments that makes communications system design for these channels challenging. One of the severe impairments is fading, which leads to a high variability in signal quality. Other impairments in wireless channels also include delay spread and co-channel interference. The use of multiple antennas at transmitter and receiver in a wireless channel can help mitigate these impairments. The leverages offered by MIMO technology are four-fold: Diversity gain, spatial multiplexing gain, and array gain and interference reduction.

- **Diversity Gain:** The idea behind diversity techniques is to provide the receiver with multiple, ideally independently diversity branches of the same transmitted signal. Diversity techniques in MIMO channels combine receive and transmit diversity.
- **Spatial Multiplexing Gain:** Spatial multiplexing (SM) gain is a unique characteristic of MIMO channels. Under favorable channel conditions, SM theoretically offers a linear increase in transmission rate and realizes the capacity gain of MIMO channels.
- **Array Gain:** Array gain is the average increase in signal power at the receiver due to the coherent combining of signals from multiple antennas at the receiver or transmitter or both. The array gain in MIMO channels is a function of the largest singular value of the channel.
- **Interference Reduction:** Co-channel interference arises due to frequency reuse in wireless channels. When multiple competitive and cost conscious market. Antennas are used, the differences between the spatial signatures of the desired signal and co-channel interference can be exploited to reduce interference.

One should note that some gain can be simultaneously achieved while others compete and establish a tradeoff. With proper signaling and receiver design, MIMO may be leveraged to extract significant performance enhancements. In a nutshell, the use of multiple dimensions at both ends of a wireless link offers significant improvements in terms of spectral efficiency and link reliability.

## III. SPACE TIME BLOCK CODES

The generalized schemes are referred to as Space-time block codes. However, for more than two transmit antennas no complex valued STBCs with full diversity and full data rate exist. Thus, many different code design methods have been proposed providing either full diversity or full data rate. If we want to increase the coding gain further, we should apply an additional high performance outer code concatenated with an appropriate STBC used as an inner code. Such schemes have been proposed e.g. under the name of Super Orthogonal Space-Time Trellis Codes. In a general form, an STBC can be seen as a mapping of complex symbols onto a matrix of dimension. An STBC code matrix taking on the following

$$s = \sum_{n=1}^{n_N} [s_n a_n + j s_n b_n]$$

## IV. BLOCK DIAGRAM

Space-Time Block Coded Spatial Modulation (STBCSM) is designed to take advantage of both SM and STBC. In the STBC-SM scheme, both STBC symbols and the indices of the transmit antennas from which these symbols are transmitted, carry information. We choose Alamouti's STBC, which transmits one symbol pcu, as the core STBC due to its advantages in terms of spectral efficiency and simplified ML detection. In Alamouti's STBC, two complex information symbols ($x1$ and $x2$) drawn from an $M$-PSK or $M$-QAM constellation are transmitted from two transmit antennas in two symbol intervals in an orthogonal manner by the codeword.

$$X = (x1\ x2) = \begin{pmatrix} x1 & x2 \\ -x_2^* & x_1^* \end{pmatrix}$$

Where columns and rows correspond to the transmit antennas and the symbol intervals, respectively. For the STBC-SM scheme we extend the matrix to the antenna domain.Let us introduce the concept of STBC-SM via the following simple example.

Example (STBC-SM with four transmit antennas, BPSK modulation): Consider a MIMO system with four transmit antennas which transmits the Alamouti STBC using one of the following four codeword:

$X_1=\{x_{11},x_{12}\}=$

$$\left\{\begin{matrix} x1 & x2 & 00 \\ -x2* & x1* & 00 \end{matrix}\right\}\left\{\begin{matrix} 0 & 0 & x1 & x2 \\ 0 & 0 & -x2* & x1* \end{matrix}\right\}$$

$X_2=\{x_{21},x_{22}\}=$

$$\left\{\begin{matrix} 0 & x_1 & x_2 & 0 \\ 0 & -x_2^* & x_1^* & 0 \end{matrix}\right\}\left\{\begin{matrix} x2 & 0 & 0 & x2 \\ x1* & 0 & 0 & -x1* \end{matrix}\right\} e^{j\theta}$$

Where $X_i$, $i = 1, 2$ are called the STBC-SM codebooks each containing two STBC-SM code words $X_{ij}$, $j = 1, 2$ which do not interfere to each other. The resulting STBC-SM code is $\chi = \bigcup_{i=1}^{2} . X_i$. A non-interfering codeword group having $a$ elements is defined as a group of code words satisfying $X_{ij} X^H_{ik} = 0_{2x2}$, $j, k = 1, 2, \ldots, a$, $j\ \ k$; that is they have no overlapping columns. Where, $\theta$ is a rotation angle to be optimized for a given modulation format to ensure maximum diversity and coding gain at the expense of expansion of the signal constellation. However, if $\theta$ is not considered, overlapping columns of codeword pairs from different codebooks would reduce the transmit diversity order to one. Assume now that we have four information bits ($u_1,u_2,u_3,u_4$) to be transmitted in two consecutive symbol intervals by the STBCSM technique. The mapping rule for 2 bits/s/Hz transmission is given by Table I for the codebooks and for binary phase-shift keying (BPSK) modulation, where a realization of any codeword is called a transmission matrix. In Table I, the first two information bits ($u_1$,u2) are used to determine the antenna-pair position ℓ while last two ($u_3,u_4$) determine the BPSK symbol pair. If we generalize this system to $M$-ary signaling, we have four different code words each having $M^2$ different realizations. Consequently, the spectral efficiency of the STBC-SM scheme for four transmit antennas becomes m= (1/2) $\log_2 4M^2$ =1+ $\log_2 M$ bits/sec/Hz, where the factor 1/2 normalizes for the two channel uses spanned by the matrices. For STBCs using larger numbers of symbol intervals such as the quasi-orthogonal STBC for four transmit antennas which employs four symbol intervals, the spectral efficiency will be degraded substantially due to this normalization term since the number of bits carried by the antenna modulation $\log_2 C$(where $c$ is the total number of antenna combinations) is normalized by the number of channel uses of the corresponding STBC.

TABLE I. STBC-SM MAPPING RULE FOR 2 BITS/S/HZ TRANSMISSION USING BPSK, FOUR TRANSMIT ANTENNAS AND ALAMOUTI'S STBC

| | | **Input Bits** | **Transmission Matrices** | | | **Input Bits** | **Transmission Matrices** |
|---|---|---|---|---|---|---|---|
| $X_1$ | **ℓ= 0** | **0000** | $\begin{pmatrix} 1 & 1 & 0 & 0 \\ -1 & 1 & 0 & 0 \end{pmatrix}$ | $X_2$ | **ℓ= 2** | **1000** | $\begin{pmatrix} 0 & 1 & 1 & 0 \\ 0 & -1 & 1 & 0 \end{pmatrix} e^{j\theta}$ |
| | | **0001** | $\begin{pmatrix} 1 & -1 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{pmatrix}$ | | | **1001** | $\begin{pmatrix} 0 & 1 & -1 & 0 \\ 0 & 1 & 1 & 0 \end{pmatrix} e^{j\theta}$ |
| | | **0010** | $\begin{pmatrix} -1 & 1 & 0 & 0 \\ -1 & -1 & 0 & 0 \end{pmatrix}$ | | | **1010** | $\begin{pmatrix} 0 & -1 & 1 & 0 \\ 0 & -1 & -1 & 0 \end{pmatrix} e^{j\theta}$ |
| | | **0011** | $\begin{pmatrix} -1 & -1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}$ | | | **1011** | $\begin{pmatrix} 0 & -1 & -1 & 0 \\ 0 & 1 & -1 & 0 \end{pmatrix} e^{j\theta}$ |
| | **ℓ= 1** | **0100** | $\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & -1 & 1 \end{pmatrix}$ | | **ℓ= 3** | **1100** | $\begin{pmatrix} 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & -1 \end{pmatrix} e^{j\theta}$ |
| | | **0101** | $\begin{pmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & 1 \end{pmatrix}$ | | | **1101** | $\begin{pmatrix} -1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 \end{pmatrix} e^{j\theta}$ |
| | | **0110** | $\begin{pmatrix} 0 & 0 & -1 & 1 \\ 0 & 0 & -1 & -1 \end{pmatrix}$ | | | **1110** | $\begin{pmatrix} 1 & 0 & 0 & -1 \\ -1 & 0 & 0 & -1 \end{pmatrix} e^{j\theta}$ |
| | | **0111** | $\begin{pmatrix} 0 & 0 & -1 & -1 \\ 0 & 0 & 1 & -1 \end{pmatrix}$ | | | **1111** | $\begin{pmatrix} -1 & 0 & 0 & -1 \\ -1 & 0 & 0 & 1 \end{pmatrix} e^{j\theta}$ |

### A. STBC-SM System Design and Optimization

In this subsection, we generalize the STBC-SM scheme for IMO systems using Alamouti's STBC to transmit antennas by giving a general design technique. An important design parameter for quasi-static Rayleigh fading channels is the minimum coding gain distance (CGD) between two STBC-SM codeword's $X_{ij}$ and $\hat{X}_{ij}$, where $X_{ij}$ is transmitted and $\hat{X}_{ij}$ is erroneously detected, is defined as

$$\delta_{min}\left(X_{ij}, X^{\wedge}_{ij}\right) = \min_{X_{ij}, X^{\wedge}_{ij}} det\left(X_{ij} - X^{\wedge}_{ij}\right)\left(X_{ij} - X^{\wedge}_{ij}\right)^{H}$$

The minimum CGD between two codebooks $x_i$ and $x_j$ is defined as

$$\delta_{min}(X_i, X_j) = \min_{k,l} \delta_{min}(Xi_k, X_{jl})$$

And the minimum CGD of an STBC-SM code is defined by

$$\delta_{min}(X) = \min_{i,j,i!=j} \delta_{min}(Xi, X_j)$$

Note that, corresponds to the determinant criterion gives the minimum CGD between non-interfering codewords of the same codebook is always greater than or equal to the right hand side of above equation.

Unlike in the SM scheme, the number of transmit antennas in the STBC-SM scheme need not be an integer power of 2, since the pairwise combinations are chosen from $n_T$ available transmit antennas for STBC transmission. This provides design flexibility. However, the total number of codeword combinations considered should be an integer power of 2.

In the following, we give an algorithm to design the STBC-SM scheme:

1) Given the total number of transmit antennas, calculate the number of possible antenna combinations for the transmission of Alamouti's STBC, i.e., the total number of STBC-SM codeword's from $c = (n_{T)}\ 2^{p}$, where $p$ is a positive integer.
2) Calculate the number of codeword's in each codebook $x_i, i = 1, 2, \ldots, n-1$ from $a = \lfloor n_T/2 \rfloor$ and the total number of codebooks from $n = \lceil c/a \rceil$. Note that the last codebook $x_n$ does not need to have a codeword's, i.e., its cardinality is $a' = c - a(n-1)$.
3) Start with the construction of $X_1$ which contains a non interfering code words as

$$X1 = \{ X0_{2X(nT-2)}\ 0_{2x2}\ X0_{2X(nT-4)}\ 0_{2x2(a-1)} X0_{2X(nT-2a)} \}$$

where X is defined in code word
4) Using a similar approach, construct $X_i$ for $2 \le i \le n$ by considering the following two important facts:

- Every codebook must contain non-interfering codeword chosen from pair wise combinations of available transmit antennas.
- Each codebook must be composed of codeword with antenna combinations that were never used in the construction of a previous codebook.

5) Determine the rotation angles for $\theta_i$ each $x_i$, $2 \le i \le n$, that maximize for a given signal constellation and antenna configuration; that is

$$\theta_{opt} = \arg\max_{\theta} \delta_{min}(x), \text{ where } \theta = (\theta_2, \theta_3, \ldots \theta_n)$$

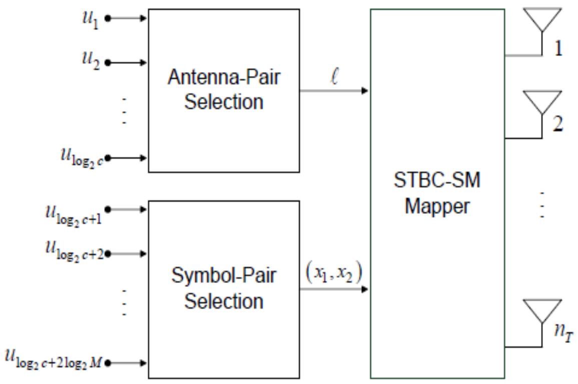


Figure 1. Block diagram of the STBC-SM transmitter

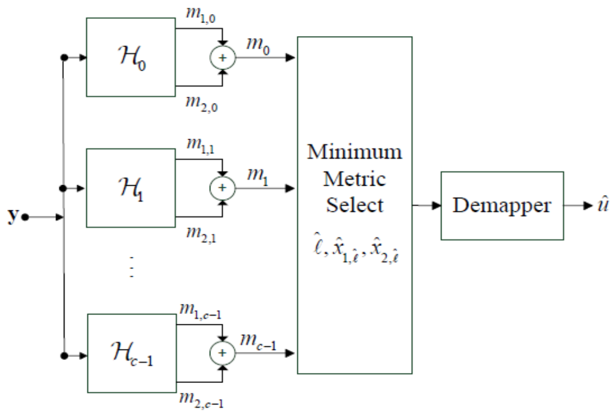


Figure 2. Block diagram of the STBC-SM receiver

### B. Performance Analysis of the STBC-SM system

The error performance of the STBC-SM system in which 2m bits are transmitted during two consecutive symbol intervals using one of the $CM^2 = 2^{2m}$ different STBC-SM transmission matrices, denoted by $X_1, X_2, \ldots, X_{2^{2m}}$. An upper bound on the average bit error probability (BEP) is given as

$$P_b \le \frac{1}{2^{2m}} \sum_{i=1}^{2^{2m}} \sum_{j=1}^{2^{2m}} \frac{P\left(X_i \to X_j\right) n_{i,j}}{2m}$$

In case of c=an, for $n_T$=3 and for an even number of transmit antennas when $n_T \ge 4$, the transmission matrices have the uniform error property due to the symmetry of the STBC-SM codebooks i.e., have the same PEP as that of $X_1$. Then the BEP upper bound for STBC-SM is given as

$$P_b \le \sum_{j=2}^{2m} \frac{P\left(X_1 \to X_j\right) n_{i,j}}{2m}$$

Applying the natural mapping to transmission matrices, $n_{1,j}$ can be directly calculated as

$n_{1,j} = \omega\left[\left(j-1\right)_2\right]$, where $\omega[x]$ and $(x)_2$ are the hamming weight and the binary representation of x, respectively. Then the union bound on the BEP is given as

$$P_b \le \sum_{j=2}^{2^{2m}} \frac{\omega\left[\left(j-1\right)_2\right]}{2m\pi} \int_0^{\pi/2} \left( \frac{1}{1+\frac{\rho\lambda_{1,j,1}}{4\sin^2\phi}} \right)^{nR} \left( \frac{1}{1+\frac{\rho\lambda_{1,j,2}}{4\sin^2\phi}} \right)^{nR}$$

## V. SPACE-TIME TRELLIS CODES

Space–time trellis codes (STTCs) are a type of space–time code used in multiple-antenna wireless communications. This STTC scheme transmits multiple and redundant copies of a trellis (or convolution) code distributed over time and a number of antennas ('space'). These multiple, 'diverse' copies of the data are used by the receiver to attempt to reconstruct the actual transmitted data. For an STC to be used, there must necessarily be multiple transmit antennas, but only a single *receive* antennas is required; nevertheless multiple receive antennas are often used since the performance of the system is improved by so doing.

In contrast to space–time block codes (STBCs), they are able to provide both coding gain and diversity gain and have a better bit-error rate performance. However, being based on trellis codes, they are more complex than STBCs to encode and decode; they rely on a Viterbi decoder at the receiver where STBCs need only linear processing.

Many different STC schemes have been proposed in the literature. Space time block codes and STTCs are two of the major classes of STCs. So-called orthogonal STBCs (OSTBCs) can achieve a maximum possible diversity advantage with a simple decoding algorithm. This simplicity has made them very attractive to researchers and system developers in recent years. However, in general, they cannot provide coding gain. In addition, for more than two transmit antennas, these codes cannot achieve full rate and thus suffer a throughput penalty. STTCs provide an effective alternative signalling technique. By having a convolution or trellis code embedded into their design (as opposed to being merely a constellation design), they can simultaneously offer coding gain, spectral efficiency, and diversity improvement on flat Rayleigh fading channels.

Space-time trellis codes encode the input scalar symbol stream into an output vector symbol stream. Unlike space-time block codes, space-time trellis codes map one input symbol at a time to an Mt×1 vector output. Decoding is performed via ML sequence estimation.

The Space-time trellis codes (STTC), is jointly designed channel coding, modulation, transmit diversity and optional receiver diversity.

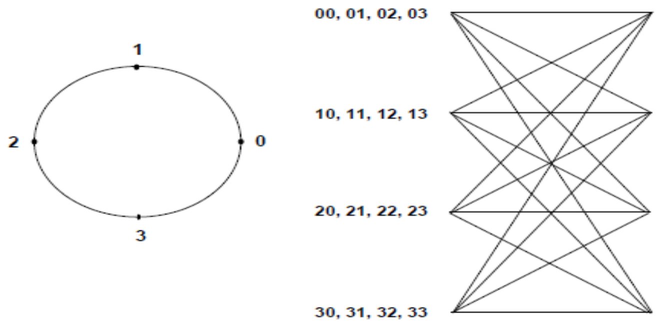


Figure 3. 4-State QPSK space-time trellis code

The figure is the trellis diagrams for 4-state QPSK STTC with two transmit antennas. The structure of space-time trellis code is given by a trellis. Here the first symbol is transmitted from first antenna and the second QPSK symbol is transmitted from second antenna, at the time instance t. Thus, at each time instance one information symbol is transmitted, and the rate is 1.The $n_R$x1 received signal is given by

$$y_t = H_t s_t + n_t$$

Where H={$h_{ji}$}, i=1,……$n_T$, j=1,……,$n_R$ is the channel matrix and s=[$s_1$,….,$s_{nT}$]$^T$ is the transmitted vector at time instance t.

A codeword **c** is given by

$$c = \begin{pmatrix} c_1(1) & \cdots & c_1(N) \\ \vdots & \ddots & \vdots \\ c_{nT}(1) & \cdots & c_{nT}(N) \end{pmatrix}$$

An error event is given by **B(c,e)=c-e.**

The probability of erroneously decoding e when c was transmitted, called pair wise error probability (PEP) is given by,

$$\mathrm{P}(c,e) \le \left( \prod_{i=1}^{r} \lambda_i \right)^{-n_R} \left( \frac{E_s}{4N_0} \right)^{-rn_R}$$

Where r is the rank of **A(c,e) = B(c,e)B$^H$(c,e)** and λ are the nonzero eigen values of A(c,e). From the above equation, the design criteria can be given as

1. Rank criterion: To achieve maximum possible diversity, $n_T$ x $n_R$, matrix A(c,e) Should be full rank for all the code words
2. Determinant criterion: To maximise the coding gain, minimum determinant of A(c,e) should be maximized over all code words.

## VI. SIMULATION RESULTS AND COMPARISIONS

The simulation is performed for different number of transmitter antennas i.e., when $n_t$=3,4 MIMO systems using STBC-SM scheme using BPSK , QPSK and QAM modulation techniques over Rayleigh Fading channels. Bit Error Rate (BER) versus average Signal-to-Noise ratio (SNR) is considered as the performance measure. Performance of different MIMO systems is compared for various combinations of modulation schemes and equalization techniques.

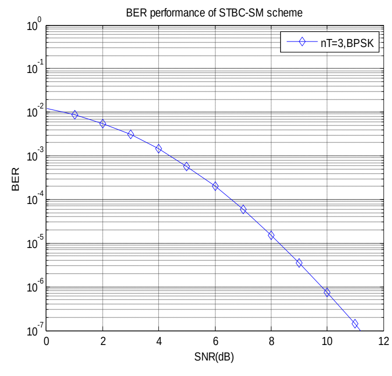


Figure 4. BER performance of STBC-SM scheme for BPSK modulation when $n_T$=3 over Rayleigh fading channel.

Fig 4 gives the plot of BER versus avg. SNR for Rayleigh fading channel using STBC-SM scheme for BPSK modulation technique. It can be observed form the plot for a given SNR, the BER value is around $10^{-2}$ when the transmitting antennas are 3.

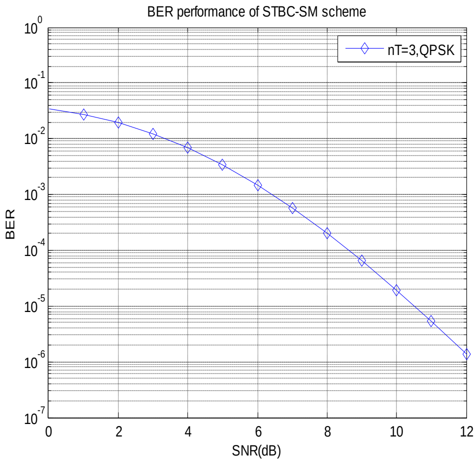


Figure 5. BER performance of STBC-SM scheme for QPSK modulation when nT=3 over Rayleigh fading channel.

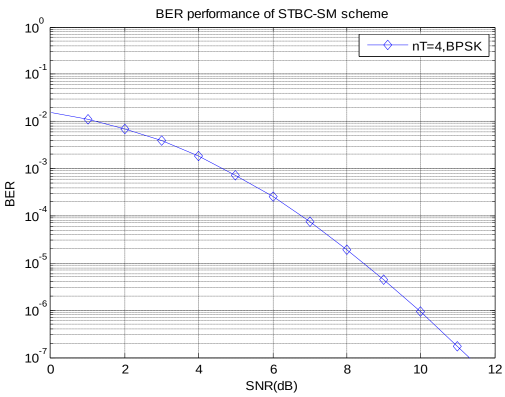


Figure 6. BER performance of STBC-SM scheme for BPSK modulation when nT=4 over Rayleigh fading channel.

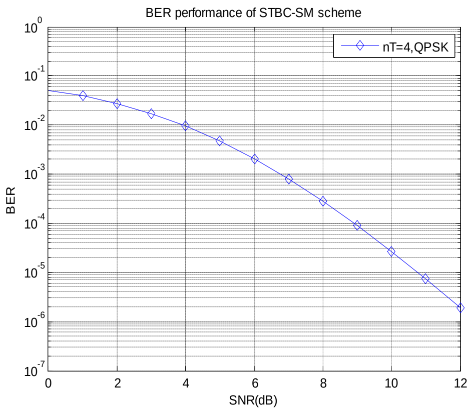


Figure 7. BER performance of STBC-SM scheme for QPSK modulation when nT=4 over Rayleigh fading channel.

Fig. 5-7 give a plot similar to that of fig. 4 but the modulation techniques are BPSK and QPSK when there are 3 and 4 transmitting antennas using STBC-SM scheme over Rayleigh fading channels.

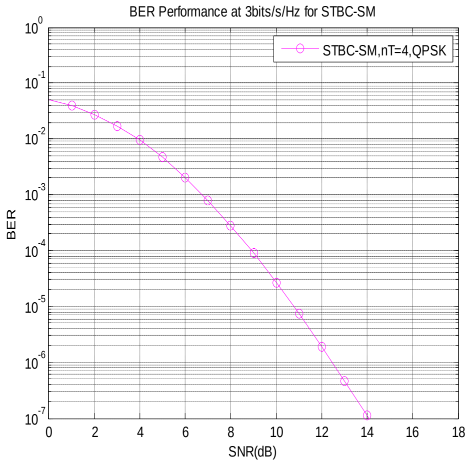


Figure 8. BER performance at 3bits/s/Hz for STBC-SM scheme for QPSK modulation when $n_T$=4 over Rayleigh fading channel.

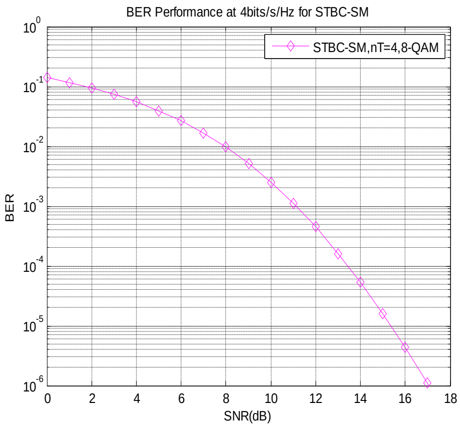


Figure 9. BER performance at 4bits/s/Hz for STBC-SM scheme for 8-QAM modulation when $n_T$=4 over Rayleigh fading channel.

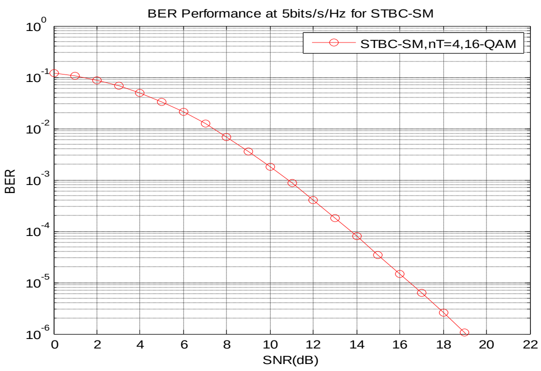


Figure 10. BER performance at 5bits/s/Hz for STBC-SM scheme for 16-QAM modulation when $n_T$=4 over Rayleigh fading channel.

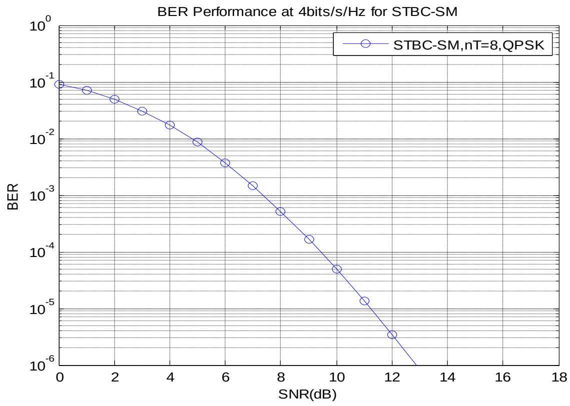


Figure 11. BER performance at 4bits/s/Hz for STBC-SM scheme for QPSK modulation when $n_T$=8 over Rayleigh fading channel.

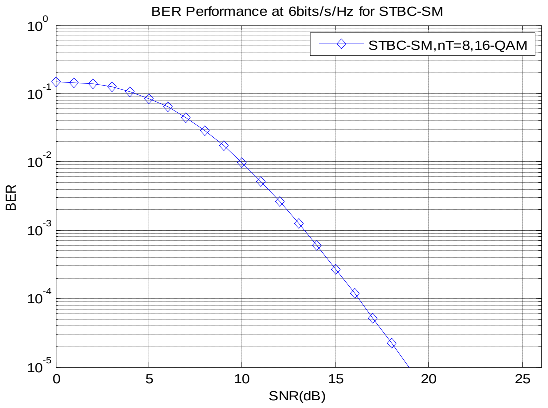


Figure 12. BER performance at 6bits/s/Hz for STBC-SM scheme for 16-QAM modulation when $n_T$=8 over Rayleigh fading channel.

Fig. 8-12 give the performance of BER vs. SNR for STBC-SM using modulation techniques like BPSK, QPSK and QAM when the bit efficiencies are 3bps/Hz, 4bps/Hz, 5bps/Hz and 6bps/Hz over Rayleigh fading channels.

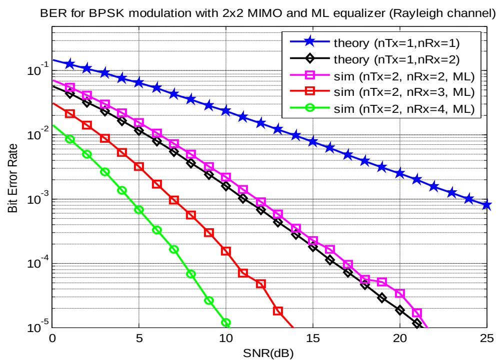


Figure 13. BER performance for BPSK modulation with 2x2 MIMO and ML equalizer over Rayleigh fading channel.

Fig. 13 shows the BER performance for BPSK modulation with 2x2 MIMO and ML equalizer over Rayleigh fading channel.

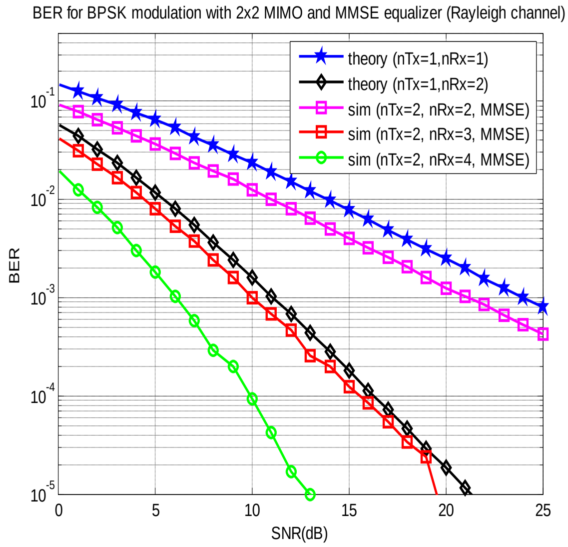


Figure 14. BER performance for BPSK modulation with 2x2 MIMO and MMSE equalizer over Rayleigh fading channel.

Fig. 14 shows the BER performance for BPSK modulation with 2x2 MIMO and MMSE equalizer over Rayleigh fading channel.

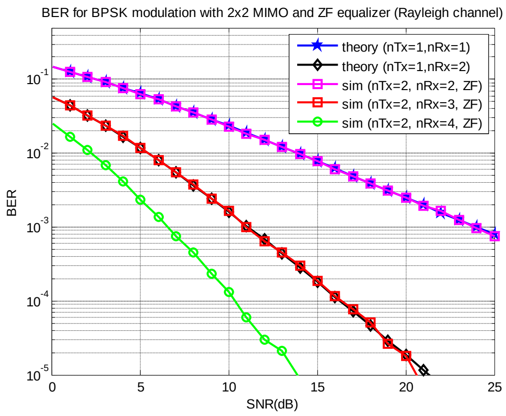


Figure 15. BER performance for BPSK modulation with 2x2 MIMO and ZF equalizer over Rayleigh fading channel.

Fig. 15 shows the BER performance for BPSK modulation with 2x2 MIMO and ZF equalizer over Rayleigh fading channel.

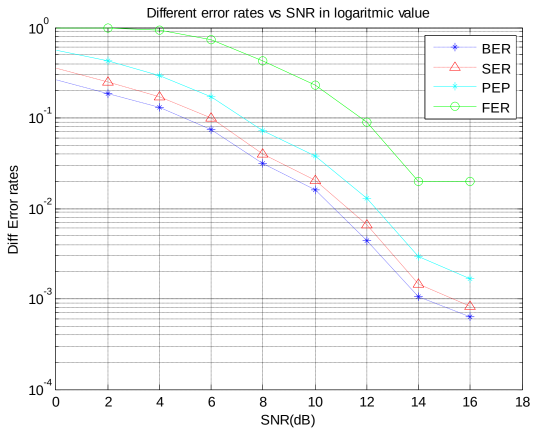


Figure 16. Different error rates vs. SNR in logarithmic value using STTC

Figure 16 shows the performance of different error rates in comparison with SNR in logarithmic value using space time trellis code.

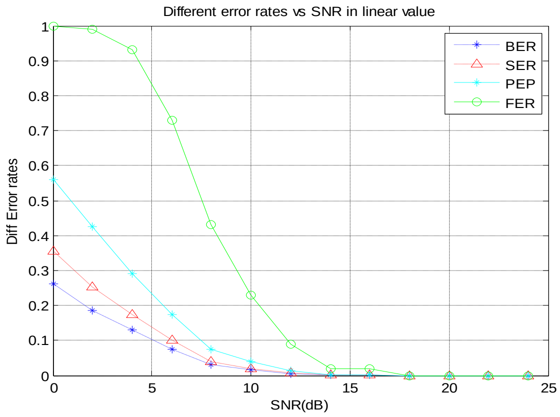


Figure 17. Different error rates vs. SNR in linear value using STTC

Figure 17 shows the performance of different error rates in comparison with SNR in linear value using space time trellis code.

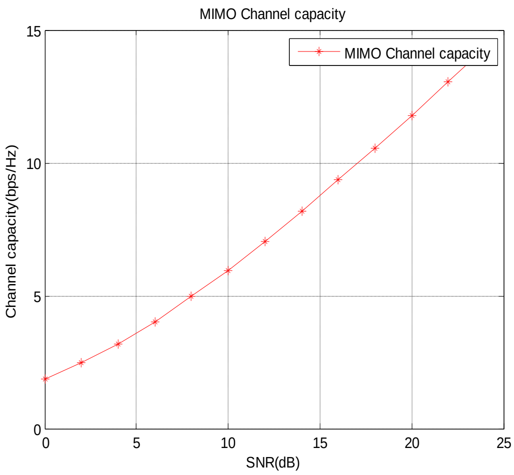


Figure 18. MIMO channel capacity

Fig 18 shows the channel capacity of a MIMO channel in comparison with SNR in logarithmic value using space time trellis code.

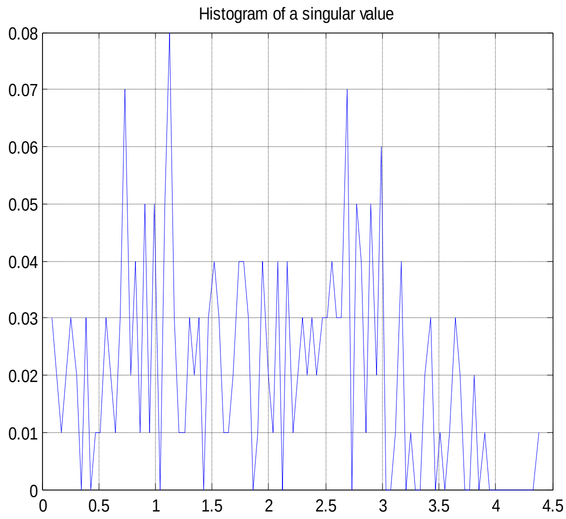


Figure 19. Histogram of a singular value

Fig. 19 shows the histogram of a singular value decomposition of each iteration within the given generated matrix.

## VII. CONCLUSION

BER performance of 1x1,1x2,2x2,2x3,2x4 mimo systems using ml,mmse,zf equalization techniques over rayleigh fading channels is investigated. Simulation results show that mimo systems with large constellation (qam and qpsk) are less efficient compared to small constellation (bpsk) and mimo systems with less number of receive antennas are less efficient compared to large number of receive antennas with similar number of transmit antennas. By the above results we can conclude that MIMO systems using STBC-SM scheme can give a reliable results even in the worst fading environment.

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